THE EFFECT OF CHANGES IN CERTAIN DETERMINANTS OF GROUND UPON THE PERCEPTION OF BETA MOTION

By

HERBERT CARLTON HART

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CHAPTER I

INTRODUCTION

The purpose of this study is to investigate the effects of certain characteristics of fixed grounds upon the perception of Beta-type motion. In perception, figure-ground relationships have been known and often reported; however, these most often involve static, unmoving perceptions (11, 28). Rarely have they been concerned with figure-ground effects in a dynamic field as represented by the phi-phenomenon (6). There have been no specific investigations of fixed variate ground effects on the perception of apparent motion of the Beta-type.

The Beta motion is a relatively simple perception which is far-reaching in its theoretical importance. If an O is presented with two flashing lights, the flash relationship being such that as one light, "A", goes off, a second light, "B", goes on, the perception may be that of a single light which moves from the first position to that of the second (36). If the relationship is continuous, i.e., ABABABAB . . . AB, the perception may be that of a single light which moves backward and forward between the two positions. It may appear to move in a two-dimensional plane, or in a three-dimensional path. This is the Beta phenomenon (33).

There are a number of variables involved as earlier experiments have shown (4, 6, 18, 24). The flash rate in terms of complete cycles per second (A on, B off; A off, B on), the duration of the pause, if any, between A and B, intensity of the stimulus lights, duration of the flashes, amount of dark adaptation prior to the presentation of the lights, distance between the lights, instructions to the O, length of the presentations, presence of figures included on the face of the stimulus lights, and the background have all been shown to be important variables (1, 2, 18, 34, 37).

The relationship of pause time between the lights, intensity, and spatial separation were further investigated by Korte (18). The formal statement is known as Korte's Laws, although some of his findings have recently been questioned (6). Korte found that a short time interval between the two exposures, a long distance between the stimulus lights, and a low intensity of stimulus lights made perception of the phenomenon difficult. No one of these conditions acts in itself; rather, there is an important interaction between the variables. Corbin (4) showed in his experiments that a long distance between the lights can be bridged by a long pause time.

There have been a number of theories attempting to explain apparent motion. Among the earliest of these was the eye-movement theory which stated that the movement of the eyes and their musculature accounted for the perception of the motion. However, Guilford and Helson (12) showed that there was no significant correlation between the reports of apparent motion and the photographic record of eye movements during the report. Wendt (35) showed that during the perception of apparent motion, the eyes were engaged in fixating objects just as in the perception of real movement.

Exner (7) proposed in 1875 a retinal neural theory to account for both real and apparent motion. It involved the interaction between elements in the retinae when the elements were successively stimulated. This interaction served to smooth into one continuous percept the stimulation of the series of discrete points in the retinae. However, the finding that apparent motion took place when one stimulus was presented to one eye and another stimulus to the other eye effectively vitiated this theory, for there could not possibly be any retinal neural interaction under these conditions (8, 31). Wertheimer (36) proposed the next step in a modification of Exner's theory. He placed the necessary interaction centrally, in the cerebral cortex, rather than peripherally, in the retinae.

There have been a number of experiments performed using only one eye, using both eyes together, and using both eyes separately (8, 31). These aimed at substantiating or refuting the neural interaction theories. If both stimulus lights are presented binocularly, then interaction of the generated neural fields could take place at any point along the visual corticopetal pathways: the retinae, the optic chiasma, the lateral geniculate nuclei, the optic radiations, or the striate cortex (Brodmann's area 17), or even in the more remote subcortical structures (23, 32). Similarly, the presence of the stimulus lights in one eye would rule out one-half of the peripheral neural system, but would not rule out any of the more central structures because of the hemidecussation of the optic tract at the level of the optic chiasma. But by presenting one light to one eye, and another light to the other eye, only the central structures could be involved in the neural interaction (37).

Gengerelli (8) investigated the effects of heteronymous and homonymous stimulation of the striate cortex in an attempt to answer this problem of interaction. By heteronymous stimulation he meant presenting the stimulus lights in such a manner as to stimulate the striate cortex in both hemispheres. Homonymous stimulation occurred when stimulation took place in only one hemisphere. He used a split-field technic by means of half-silvered mirrors. He presented different stimuli to each eye. Underlying this technic is the assumption of spatial projection of areal stimulation through the optic chiasma, the lateral geniculate bodies, the optic radiations, and the striate cortex, with the preservation of patterning in all these structures (23). Under these conditions, he found that his Os saw the largest amount of apparent motion under the homonymous condition. He ascribed his findings to the interaction of neural fields taking place in the cortex, and not in the subcortical structures of the visual corticopetal pathways. However, his findings were questioned by Smith (31).

Smith (31) presented his Os with two lights which were mounted on a headband. The lights were adjusted in such a manner that the images formed by the lights were on the extreme nasal borders of the retinae. Only one light could be seen by either eye. This mode of presentation resulted in the stimulation of the extreme borders of the striate cortex, bordering on the calcarine fissure. This stimulation thus gave the maximum possible separation of the areas of stimulation of the cerebral cortex. Nevertheless, he obtained from his Os good perception of apparent motion. He interpreted his findings as ruling out neural field interactions on both the peripheral and central levels.

Because of the peculiar spatial projection in the optic chiasma, he felt that the required interaction could not have taken place at that level. Moreover, he interpreted his findings as contradicting the usual Gestalt theory of apparent motion. The later study by Corbin (4) may provide a better frame of reference for the interpretation of these findings than that used by Smith himself.

Corbin (4) presented his _Os_ with the stimulus lights arranged as fronto-parallel lines at various distances, and then presented them with similar lines slanted at 60° from the vertical. By so slanting the lines, the actual retinal separation of the stimulus lights involved only half the distance apart in the second as in the first presentation. He obtained the same time thresholds with both types of presentations. These thresholds should have dropped markedly in the second presentation because of the lessened spatial separation, if Korte's Laws hold. He interprets his findings as being quite difficult to reconcile with Wertheimer's (36) theory of isomorphism which seems to demand an actual physical separation of the areas of stimulation in the cortex that represents the analog of the physical separation of the stimuli in space.

What does seem important in the interpretation of these findings is that it is not the physical separation of the areas of stimulation but rather the perceptual separation which governs the limens obtained. This reinterpretation of the findings would bring them into consonance with the Gestalt theory. Ellis (6) considers the phenomenon a function of the entire field as an integrated Gestalt. It is not the product of any one variable _in vacuo_. Moreover, he would apply this theory equally to the neural fields of the central nervous system as well as the perceptual field. The entire mosaic, then, from the external stimulus field through the receptors, the corticopetal mechanisms, and the cortex itself, all enter into the final perception: these together constitute the functional whole.

The effect of the ground upon the perception of figures contained within that ground has had a long history in psychology, but has been explored most extensively by the Gestalt writers (6). Early work included that of Rubin (28), Gottschaldt (10, 11), and Koffka (16, 17). In general, Rubin worked upon the effects in perception of the reversible figure-ground illusions. Gottschaldt did most of his work with concealment of figure in ground. These effects were all in static fields, however. Koffka dealt more with the effect of ground in dynamic fields, as in the perception of apparent motion. We will detail two approaches here: that of Duncker (5) and one of Koffka's (16) which deal with the dynamic field percepts.

Duncker's work dealt with induced motion: the perception of motion produced in one figure by the motion of another in the field, and the motion produced in the figure by the motion of the field against which it was seen. In his experiment, he exposed successively by means of a tachistoscope two rectangles with dots placed upon them. The dots alone were superimposed in successive presentations, first in one and then in a second rectangle. In another series of experiments, neither the dots nor the rectangles were superimposed. His findings indicated that the fixated figure was the more susceptible to the induction of motion. The enclosed, rather than the enclosing figure, showed the greater tendency toward induced motion. It seems reasonable to interpret his findings as dealing with figure-ground relationships. The fixated figure can be considered to be in sharp focus, the non-fixated figure less so. The one is seen as figure, while the other tends to become ground. His findings then indicate that the ground is stable, but that the figure is susceptible to the induction of motion. The ground may be considered to form an anchor for the figure: the figure is seen to move against a ground. If the fixated figure is the enclosing figure, then motion is less likely to be induced. This seems to indicate that the enclosing figure, although fixated, is yet seen as ground, and not as figure. However, this interpretation seems the most logical one in terms of the Gestalt principle of prägnanz. Hartmann (13), while he discussed the experiment, does not answer this interpretation, nor does Duncker.

The experiment Koffka (16) performed was in refutation of Linke's (20, 21) earlier work. Linke's Os were presented with a perisphere (a semicircle with a depressed center, the arms pointing up) on which was drawn a dot. In a succession of presentations, the dot was placed in a series of intermediate positions around the perisphere. The perception was that of a dot rolling around in a semicircle against a fixed ground. Linke interpreted his findings as being an interpretation of the percept by the O based upon his past experiences, e.g., such as seeing a ball roll around the inside of a bowl. Apparent motion, for Linke, was not a given fact, but was inferred from past experience.

Koffka (16), in a neat reversal of the experiment, refuted Linke's interpretation but confirmed his findings. Koffka presented his Os with a similar design, but with the apex of the perisphere pointing upward and the arms downward. The perception reported by his Os was exactly the same as those reported by Linke's, but, of course, past experience could not now be considered a basis for the percept. Hence, Koffka considered apparent motion a given, not a learned, fact. Koffka went further, however. He presented his Os with the dots in exactly the same position as before, but without the perisphere. This time the percept was of a series of dots jumping about; they no longer rolled smoothly from one position to the next. He interpreted his findings as meaning perception is a function of the entire field, and not of one part of the field without consideration of the remainder.

These experiments show without question that there are definite effects upon the perception of apparent motion of the changes in the ground against which the figure is seen. This has, of course, been known a long time in the studies of perception of static fields. Early investigations noted that some figure properties in form perception of apparently moving objects were influential in perception. Reichenberg's study (27) indicates that in the duration of perceived motion significant differences between all combinations of figure patterns were not obtained. Neither in terms of mean time for perceived motion nor in total time of perceived motion of two lighted figures in motion was form a significant variable. In an analysis of mean time for perception of one lighted figure in motion, e.g., optimal movement, form was significant in the F test. An F test for analysis of variance of total time of perceived motion was not significant. Thus, figure is important in some measurements of apparent motion but not in all.

If the figures are different in form or in color, this difference may become an important variable in the perception of apparent motion. Orlansky (25) explored these variables. He found that if the stimulus lights are shown in the form of two arrows pointing in the same direction, motion is easily seen by most _Os_; it is quite compelling, and is very realistic. But if one arrow points to the right and the other to the left, it becomes much more difficult to perceive apparent motion, and it is easily lost. More time must be allowed between flashes (i.e., by increasing the pause time or by decreasing the flash rate) if apparent motion is to be seen. Even so, a considerable number of _Os_ cannot obtain good motion under these conditions. Ellis (6) explains this phenomenon under the headings of _prägnanz_ and of common destiny. Reichenberg (26, 27) carried out an additional study in this area. His findings in general confirmed those of Orlansky although he used very different stimulus figures.

The phenomenon of apparent motion is not limited entirely to the use of alternate lighted areas, although this mode of presentation has been the most common in the past (33). Brown (3) found that a similar phenomenon was obtained in the perception of real motion under certain conditions. Brown used a continuous strip of paper to which black rectangles had been applied, and varied the speed of rectangles moving past a slot. A mask concealed the remainder of the strip. The _O_ observed the movement. When the paper was moving at a high rate of speed past the slot, the rectangles were perceived as a continuous band of gray. At low speeds, the rectangles were reported as moving in the direction of their real motion. At certain intermediate speeds, the _Os_ reported the rectangles moving in a direction opposite to the direction of their objective movement. Brown interpreted his findings correctly as a true example of apparent motion.

The purpose of the present study is to investigate the effects of certain determinants of ground upon the perception of Beta motion. It has been shown in a number of experiments that ground has an important effect on the percept. There are a number of determinants of ground and figure relationships detailed by the Gestalt writers. Among the principles determining the percept of figure are those of clearness: the figure is more sharply defined than is the ground. The ground is the less distinct of the two, and tends to be ignored in reports of the percept. The figure is more interesting or lively than the ground, and seems to stand out from the ground; the ground seems to continue behind and to be hidden by the figure. These principles are grouped under the general heading of _prägnanz_: the meaningfulness of the parts of the percept (6, 16).

A second principle is that of common destiny: the figures and the ground seem to share an end common to both. Thus, if a vertically barred ground is presented against which Beta motion is to be seen, these vertical bars can be thought to share a common destiny with the percept of apparent motion (6, 16). Under the principle of _prägnanz_, such a ground should form a barrier to the continued perception of apparent motion because it forces the apparently moving stimulus lights to cross successively a series of dark and light stripes. Conversely, a ground which contains stripes of light and dark arranged horizontally so that the stripes lie parallel to the anticipated path of apparent motion should facilitate the percept by forming pathways. A similar percept seems to have occurred in Koffka's (16) experiment.

A third principle with which this experiment deals is the Gestalt principle of isomorphism: the representation in neural elements of the sensory stimulus with preservation of the Gestalt of that stimulus field (6, 16). Thus, translating the previously presented models into isomorphic terms, one would expect that the vertically barred ground would stimulate selectively neural elements, and that there would be a preservation of its form in the patterning of the stimulation. For example, such a ground as the vertically barred one discussed previously, would set up alternating bands of excitation and quiescence in the striate cortex in an exact analog of the original stimulus. Such a continuing stimulus as is presented by Beta motion would produce an interacting neural field such that a continuous band of excitation would cross and recross the cerebral cortex in exact neural representation of the percept of the motion as reported by the _O_.

If the interaction of neural fields set up by the stimulus lights is necessary for the percept of apparent motion to take place as is demanded by the Gestalt theory, then it seems likely under the principles just outlined that certain types of cortical fields should act to inhibit or to facilitate the perception of apparent motion. In line with a Gestalt theory of apparent motion, bands of quiescence and excitation should be set up in the cortex (strictly speaking, in the neurons making up the cortex) by that ground corresponding to the arrangement presented by that ground in visual space, and these hypothetical bands should have an important effect on the perception of apparent motion (2, 23).

A position for the derivation of three hypotheses has been established. The next step is to design an experiment to test them. First, it may be anticipated that the non-figured, i.e., plain, ground will provide the least interference with apparent motion. It will do this because, under the principle of isomorphism, it will consist only of uniformly excited neurons. Because it poses no barriers to the perception of apparent motion, it is anticipated that it will provide the largest flash-rate range of apparent motion. If the upper flash-rate threshold for apparent motion is measured, it should follow that this value is increased: the _O_ is able to perceive apparent motion at a higher flash-rate before it breaks down. It should also follow that the _O_ could perceive apparent motion at a lower flash-rate: the lower flash rate limen should be decreased. The net result should be an increase in the range of flash-rates within which apparent motion may be perceived.

Secondly, if a vertically barred ground against which apparent motion is to be seen is used, it is anticipated that such a ground should form a barrier to the perception of apparent motion. In the cortex, under the principle of isomorphism, it is expected that alternating bands of excitation and quiescence corresponding to the alternating bands of dark and light on the ground would be set up. Since a horizontally moving light is produced in the apparent motion apparatus, this means that the band of excitation set up by such a percept in summating neural fields is forced to cross the alternating bands of excitation and quiescence in the cortex. It is anticipated, then, under the principles of neural summation, that this should require more energy. It may be expected that the range of flash-rates within which apparent motion is seen may be restricted if both of these operate in conjunction. This restriction should take place by raising the lower flash-rate threshold, and lowering the upper limen.

Thirdly, horizontally barred grounds may be used, furnishing the ground against which the apparent motion is to be seen. These should then set up in the cortex an analog of the spatial arrangement of the original stimulus. Accordingly, the bands of excitation created by the stimulus lights of the Beta motion apparatus will be arranged parallel to these bands of excitation and quiescence. It would be expected, then, under the principles already stated, that these bands should form perceptual pathways along which the percept may travel; thus, the perception of apparent motion under this condition should be facilitated. This facilitation may appear as an increase in the flash-rate range within which the Beta-type motion may take place. This increase in the range should occur because such facilitation will tend to lower the lower flash-rate threshold, and to raise the upper flash-rate limen.

To summarize these hypotheses, then, it is anticipated that (1) the greatest range of flash-rates within which apparent motion can be perceived will be of the non-figured ground; (2) the vertically barred ground will inhibit to the greatest extent the perception of apparent motion; and (3) the horizontally barred ground will occupy an intermediate position between these two.

CHAPTER II

APPARATUS AND PROCEDURE

Apparatus

The apparatus divides into the following: the electronic switch, the stimulus lights and grounds, and the recording equipment.

Beta motion apparatus.--This part of the apparatus consisted of an electronic switch controlling two Sylvania R1130B electronic glow tubes, the stimulus light sources. The switch used was described by Saucer (30). It is a wide-band, high-gain pentode r-f amplifier in a multivibrator circuit. The gating signals produced are square, having a negligible rise and decay time. Cathode coupling is used to the R1130B tubes to preserve this wave-form. The circuit is stable to 15 kilocycles (kc); it is normally operated well within this margin. Several flash-rate ranges are provided in the control switch, giving rates from 0.2 flashes per second (f/s) to 30.5 f/s.

The second portion of the apparatus included the stimulus lights, the equipment used to support and illuminate the grounds, the lens associated with the R1130B tubes, and the diffusing screens. The Sylvania R1130B glow tubes provide a sharp response up to the ionization value of the tube which is approximately 15 kc. The actual decay and rise time of the light stimulus is on the order of 2 to 3 microsec. The light output of the tube varies linearly as the plate current.

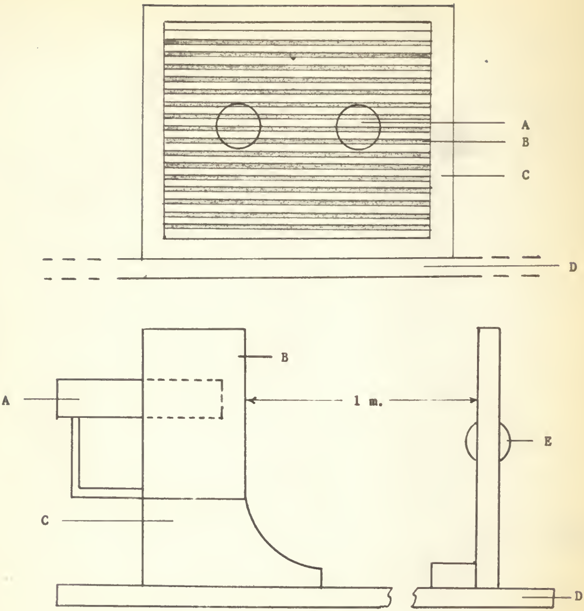
At approximately 35 milliamperes (ma.) it yields approximately a daylight spectrum. As the plate current is decreased, the emitted light shifts toward the long wave-length end of the spectrum, i.e., toward the reds. Firing of the tube becomes erratic below 5 ma. plate current. The brightness of the two tubes was equated psychologically, rather than by matching plate currents. It was found that slight differences between tubes in light output at identical plate currents preclude the use of plate current measurements alone being used to equate the lights. Plate currents in this study were held between 12 and 15 ma. In mounting the R1130B tubes in the light panel, a lens system was used to provide parallel emission of the light rays on the diffusing screen. An aperture was designed to limit the visual angle subtended by the stimulus lights to 5° at one meter (m.) from the O; however, due to diffusion through the ground glass screen, the angle was approximately 8°, as measured at the outer limit of the disc of light.

Three grounds were constructed for use in this study. One was plain, i.e., non-figured. A second consisted of parallel, opaque and translucent 7 mm. stripes in a horizontal arrangement alternately placed. The third was constructed with stripes of same width alternating opaque and translucent vertical bands. These grounds were constructed by gluing 7 mm. strips of black construction paper spaced at 7 mm. to Velox tracing paper. The black stripes were quite opaque, very sharp, and of equal width throughout their length. The Velox tracing paper provided a grainless, translucent area through which was projected the light from the R1130B tubes, and the light used to illuminate the grounds. These grounds were enclosed in a heavy cardboard frame. The grounds were all 26.8 cm. by 31.9 cm., subtending 10.2° vertical and 13.0° horizontal visual angles at one m. from the O.

These grounds were mounted in a slide in the front of a light-tight box which contained, in addition to the R1130B tubes and their lens systems and apertures, a 26.8 cm. by 31.9 cm. ground-glass diffusing screen and two 15 watt incandescent bulbs, red in color and tubular in shape, which were mounted vertically on each side of the screen. The brightness of the ground illumination was controlled by varying the voltage across the tubular lamps by means of a Variac transformer. The voltage was maintained at 12 volts (v.) throughout the study. The illumination was red for the grounds in order to maintain the O's dark adaptation at a stable level (29, 38).

The entire light panel, the ground support, and the O's chin rest were inclosed in a light-tight tunnel mounted on an optical bench. The distance from the light panel to the O's chin rest was maintained at one m. A block diagram of the light panel is shown in Fig. 1.

The optical bench, the E's booth, and the entire room were all painted flat black to absorb light. Considerable care was taken to prevent light leakage from the E's booth--necessarily illuminated in the course of the experiment--or from external sources. Leakage would naturally vary the adaptation level of the O during the course of the experiment. It should be noted, however, that the mean duration of motion perceived during periods longer than 4 min. of dark adaptation is relatively constant (38) and mean duration is not significantly changed by changes in illumination within the range used (30). A



Legend:

A - R1130B Stimulus Light
B - Ground (Horizontally Barred Ground Illustrated)
C - Light Panel Support
D - Optic Bench
E - Chin Rest

Fig. 1.--Block Diagram of the Light Panel

block diagram of the room and apparatus is shown in Fig. 2.

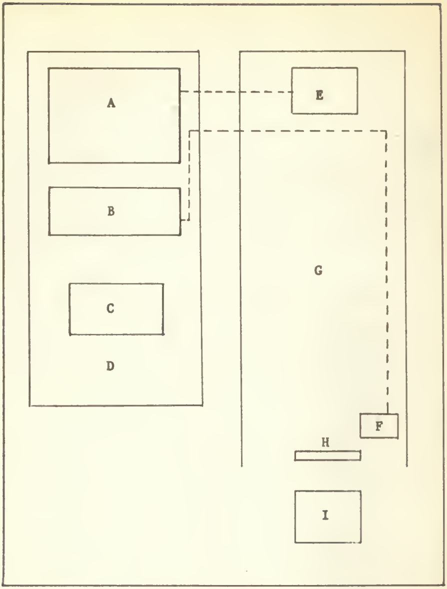
Recording apparatus.--A telegraphic key was mounted conveniently for the O within the optical bench tunnel and connected through a suitable power supply to the recording relay of a Gerbrand waxed-paper-tape signal recorder. The O placed distinctive signals on the tape at the beginning and end of each trial. These were used to locate each trial. During a trial, O pressed the key down as long as he was perceiving Beta motion. Since the paper tape was fed through the recorder at a constant speed, distance along the tape was translated to time and the amount of apparent motion reported under each condition was then computed.

Procedure

Observers consisted of 36 young adults of college age who showed no obvious signs of brain damage.

Each O was given instruction and several orientation trials prior to the beginning of the experiment proper. During this period no ground or rate used in the experiment was presented to the O. It was found that most Os had considerable difficulty in differentiating Beta motion from the shadow-motion phenomenon at the higher flash-rates. Considerable training was found necessary for the O to render an accurate, reliable report of his perceptions. During these orientation trials, the Os were instructed in the use of the telegraph key controlling the Gerbrand recorder.

Each O was given four min. of dark adaptation prior to the beginning of the experiment proper.



Legend:
A - Electronic Control Switch
B - Gerbrand Paper Tape Recorder
C - _E_'s Position
D - Light Tight Equipment Booth
E - Stimulus Light Panel
F - Gerbrand Recorder Control Key
G - Optic Bench
H - Chin Rest
I - _O_'s Position

Fig. 2.--Block Diagram of the Experimental Room

Of necessity, the instructions were varied in content for each O, for some were more familiar than others with the phenomenon. In all cases, the essential Aufgaben were constant. More accurate results were obtained by equalizing the practice effects among Os. Each O was allowed to become thoroughly familiar with the characteristics of Beta motion at each flash-rate. Although the content of the instructions was varied with these Os, the instructions were designed to instill a similar Einstellung in each O. Following this period, the experimental observation began.

Os were assigned to a Graeco-Latin Square in seriatim order (19). (See Appendix A.) Although Gilbert (9) had shown practice may be of some importance in the perception of apparent motion, a more recent study by Reichenberg (27) indicated that mean duration of motion was not significantly different during three successive practice periods. However, the use of this type of experimental design provides a control of this variable, since each ground was presented in each ordered position an equal number of times.

The use of this experimental design also provided the schedule for the presentation of all grounds to the Os. The presentation of each ground then was of a descending and ascending series of nine flash-rates. These rates were 0.4, 1.5, 2.5, 3.5, 4.5, 5.5, 6.5, 7.5, and 8.5 f/s. The use of counterbalanced series was designed to preclude any systematic error on the part of the O due to anticipation or perseveration (39). All Os were given these series for each ground. Thus, O observed a total of 18 periods for each ground, or a total of 54 times for the three grounds.

During each trial, the *O* was instructed to hold the telegraphic key down during the time he was perceiving Beta motion, and to release it when the perception was of two lights flashing, one fixed light on with the other off in cycle, or the shadow-motion phenomenon. The use of the key in this manner placed a distinctive record of Beta motion upon the Gerbrand tape. Since the tape was driven at a constant speed, a simple transformation converts distance along the tape to a time measurement. Each minute trial of motion is then converted to a per cent time by the equation:

$$t_{\%} = \frac{d_{mm.}}{D_{mm.}} (100)$$

in which $t_{\%}$ is the amount of apparent motion each subject perceived during a trial, $d_{mm.}$ is the distance along the tape during which he held the key down (was perceiving motion), and $D_{mm.}$ is the total distance along the tape of each trial (time). The product is expressed as a percentage of the time in which apparent motion was perceived.

CHAPTER III

RESULTS

Each O was presented all of the three grounds. The order of presentation is shown in the Graeco-Latin Square (Appendix A). Nine flash-rates, arranged in ascending and descending series, were used to determine the upper and lower thresholds, optimal flash-rate, and the range. These four observational variables constituted the measures of the O's perception of apparent motion used in this study. The amount of Beta motion seen at each rate and for each ground was determined from measurements taken from the Gerbrand waxed-paper-tape and then converted to time. These measures were entered in a table which was used to determine the thresholds by linear interpolation. Optimal motion was derived from the table as a modal score. The range was derived as the difference between the upper and lower thresholds; it thus represents a flash-rate range within which apparent motion may be perceived under these conditions. In determining the thresholds, the 50 per cent limen was used.

Several criteria were found necessary in screening the data. It was considered essential that each O see motion for at least half the time for one rate. A second criterion was that O should be able to report consistently. Thus, an O who exceeded the threshold, continued for a flash-rate above the threshold, and then saw less than 50 per cent motion, only to return above the threshold, was considered not to have followed the directions, and was eliminated from the study. For each O lost from the study, a replacement O was completed. The criteria for the replacement O were the same as for the original O, and the new O was placed in the same cell of the Graeco-Latin Square.

The upper and lower flash-rate thresholds, optimal flash-rate, and the range within which Beta motion is seen constituted the measures used in this study. The lower flash-rate threshold for Beta motion is defined as that rate below which the O reports less than 50 per cent apparent motion. Below threshold, psychologically, the percept breaks down into two lights which are alternately illuminated. Similarly, the upper flash-rate threshold may be defined as that rate above which Beta motion is not seen. For this study, "not seen" is defined as a report of Beta motion for less than half the time in any one trial. Again, at the threshold the typical Beta motion percept is replaced by an entirely different one; in this case, an O reports seeing two lights which are simultaneously on and flickering.

Optimal flash-rate is defined as that rate which produces the greatest reported amount of Beta motion, expressed as a percentage of the total. Thus, it is a rate at which the motion is seen most continuously by the O, and in which the motion most nearly approaches the percept of real motion.

The statistical analysis of the data included the computation of the means for all the groups for the three grounds, the standard deviations of the distributions, the standard errors of the means, Pearson product-moment correlation coefficients, t ratios based on the correlation coefficients, and four complex analyses of variance (19, 22).

The means were computed according to the standard formula given in McNemar (22) and are reported in Table 1. For the lower flash-rate threshold, the mean rate may be interpreted at that value below which Beta motion is not seen. Thus, for the non-figured ground, the value is 1.71 f/s. The value of the lower limen for the vertically barred ground is 1.77 f/s, and for the horizontally barred ground, 1.75 f/s. The upper threshold's mean value may be interpreted as being that value above which Beta motion is not seen. For the non-figured ground, this value is 5.26 f/s, while for the horizontally barred ground it is 4.68 f/s, and for the vertically barred ground it is 4.62 f/s.

The optimal rate has been defined as the rate at which the O saw the greatest per cent time of apparent motion, using the modal value. For the non-figured ground, this was 3.21 f/s. For the horizontally barred ground, the value was 3.10 f/s, while for the vertically barred ground it was 2.93 f/s. It was at these values that most Os saw the largest amount of apparent motion.

The range, the difference between the upper and lower limens, summarizes as a single value the range of rates in this study at which Beta motion was seen. These ranges, also reported in Table 1, for the non-figured ground was 3.55 f/s, for the vertically barred ground was 2.85 f/s, while that for the horizontally barred ground was 2.93 f/s.

It was desired to obtain some estimate of the dispersion around these values. To evaluate this, the standard errors of the means were computed (19, 22). These give an estimate of values within which, at a stated fiducial limit, the true mean of the universe of means from which these obtained means were drawn. Setting these fiducial limits

TABLE 1

MEASURES OF BETA MOTION ACCORDING TO GROUND PROPERTIES

	N	$\bar{X}$	σ	$\sigma \bar{X}$
Upper Flash-Rate Threshold				
Non-figured Ground	36	5.26	1.07	0.18
Horizontal	36	4.68	1.44	0.24
Vertical	36	4.62	1.46	0.24
Optimal Flash-Rate				
Non-figured Ground	36	3.21	0.86	0.14
Horizontal	36	3.10	1.00	0.17
Vertical	36	2.93	0.80	0.13
Lower Flash-Rate Threshold				
Non-figured Ground	36	1.71	0.70	0.12
Horizontal	36	1.75	0.60	0.10
Vertical	36	1.77	0.66	0.11
Range of Motion				
Non-figured Ground	36	3.55	1.36	0.23
Horizontal	36	2.93	1.67	0.28
Vertical	36	2.85	1.62	0.27

at $\pm 1\sigma$, it may be stated that the true mean rate for the upper threshold of the non-figured ground was 5.26 f/s, ± 0.18 f/s. The lower threshold was 1.71 f/s, ± 0.12 f/s, and the mean optimal rate was 3.21 f/s, ± 0.14 f/s. The range of rates within which apparent motion is seen was 3.55 f/s, ± 0.23 f/s. Similar statements may be made for the mean rates for upper thresholds, lower thresholds, optimal rates, and the range of rates within which apparent motion is seen for the other grounds.

The standard deviations of the distributions for the various grounds and measures of Beta motion were computed according to the standard method given in McNemar (22). These values are summarized in Table 1. Thus, for the upper threshold of the non-figured ground, the mean was 5.26 f/s, ± 1.07 f/s. Similar interpretations hold for the other values and for the various grounds.

The number of *Os* entering into these computations was, in all conditions, 36.

Pearson product-moment correlation coefficients between pairs of measures were computed according to McNemar's (22) model and are reported in Table 2. These may be interpreted as measures of the consistency with which the *Os* reported from one measure to another for the various grounds. They are in a sense a measure of the stability of the measures themselves, if it can be assumed that the *Os* were consistent in their reports. Presumably, a perfectly stable measure, coefficient of 1.00, should yield the same performance value irrespective of the conditions under which it operates. Any inconsistency then would be a divergence toward zero from this correlation. As may be seen from the

TABLE 2

CONSISTENCY OF GROUND EFFECTS FOR LOWER AND UPPER FLASH-RATE THRESHOLDS, OPTIMAL RATE, AND RANGE OF BETA MOTION

Measure	Ground	Vertical Ground	Horizontal Ground
Lower Flash-Rate Threshold	Non-figured	0.72**	0.64**
	Vertical	-	0.63**
Optimal Flash-Rate	Non-figured	0.41*	0.02
	Vertical	-	0.48*
Upper Flash-Rate Threshold	Non-figured	0.53**	0.53**
	Vertical	-	0.56**
Range of Motion	Non-figured	0.53**	0.53**
	Vertical	-	0.62**

*Significant at the 0.01 level of confidence, df = 36.

**Significant at the 0.001 level of confidence, df = 36.

table, these measures are fairly stable with only one exception. This exception occurs at the optimal rate for the non-figured ground correlated with the Os' reports for the horizontal ground. From the other coefficients for this measure, it will be seen that they, while significant, are significant only at a much lower level of confidence than are the coefficients for the other measures. It would appear, then, that this is the least stable of the measures used. It should be remembered that this measure was computed from a modal number of the per cent of motion seen. It was thus based upon only one score for each O, the threshold values were based upon three values by means of a linear interpolation from the data as entered in a computation table. It was noted that the instability inherent in using only one score is probably indicative of the source of this inconsistency of the O's report. It may be concluded, then, that this inconsistency may be an artifact of the method of computing this measure. It may be further concluded that the other measures are relatively stable.

The Pearson product-moment correlation coefficients were further evaluated by means of the t ratio. The formula presented in McNemar (22) was used. These correlation coefficients were tested against the null hypothesis (that there was no significant difference between the obtained correlation coefficients and zero). In all but the one case already noted, the null hypothesis was rejected at the .01 level of confidence or better.

Four complex analyses of variance were completed for this study (19). In each of these there were three fixed and one randomly distributed variable. These analyses were designed to fix the source of variance of the measures. According to the experimental design used, the significance of the effects could be evaluated for three sources: the grounds, the order of presentation, and the double interaction of the grounds and order of presentation. The measures, lower threshold, upper threshold, optimal rate, and range of rates within which Beta motion was seen, were all designated as dependent variables; each measure provided a separate analysis of variance. Ground and order of presentation, two of the three dimensions, were fixed variables. The third variate was a random variable, replication. This type of design permits the evaluation of the grounds, of the order of presentation of the grounds (practice), and of the interaction of these two. Evaluation of individual differences is not obtainable. It was assumed that individual differences would be randomly distributed and would therefore not make an important contribution to the variance in this design. Since there was only one individual assigned to each cell under this experimental design, within cell variance was zero.

The first of these analyses, that of the lower threshold by grounds by order of presentation by replications, is presented in Table 3. It is evident that there were no statistically significant sources of variance between the variables. It may be concluded that ground was not a significant variable in the determination of Beta motion for the measures used at the lower threshold.

It should also be noted that there were no statistically significant practice effects (order of presentation). The control of practice effects by assignment of _Os_ in a seriatim order to a Graeco-Latin Square was effective.

TABLE 3

ANALYSIS OF VARIANCE FOR VARIABLES MODIFYING LOWER FLASH-RATE THRESHOLD: GROUNDS X ORDER OF PRESENTATION X REPLICATIONS

Source	ss	df	ms	*F* ratio	*F*	*p*
Grounds (G)	0.07	2	0.04	ms_G/ms_{GR}	.36	-
Order of Presentation (O)	1.54	2	0.77	ms_O/ms_{OR}	.60	-
Replications (R)	6.30	11	0.57	-	-	-
G X O	0.37	4	0.09	ms_{GO}/ms_{GOR}	.60	-
G X R	2.47	22	0.11	-	-	-
O X R	28.35	22	1.29	-	-	-
G X O X R	6.78	44	0.15	-	-	-
Within Cells	0.00	0	-	-	-	-
Total	45.88	107	-	-	-	-

The effects of order of presentation and of the ground upon the measurement of optimal flash-rate of apparent motion are presented in Table 4. It may be seen that none of the variables approached statistical significance. Therefore, neither order of presentation nor ground was a significant source of variation in the determination of this measure of Beta-type of apparent motion.

The third analysis of variance is presented in Table 5. The fixed variables were order of presentation and ground. Replications formed a randomly distributed variable. The upper flash-rate threshold of Beta motion was the dependent variable. As may be seen from the table, the grounds were significant source of variance upon the Beta motion at its upper threshold ($p < .01$). It may be concluded that the grounds were a significant determinant of this measure. Again, the order of presentation (practice effect) was not a significant source of variance, nor were the interactions. The grounds alone form the major source of variance.

The last analysis of variance on the range of rates within which Beta motion was seen is presented in Table 6. Of the sources of variance in this measure of Beta motion only the grounds were statistically significant ($p < 0.025$). It should again be noted that there was no statistically significant variation attributable to the order of presentation of the grounds. Nor was the interaction of the ground and order of presentation statistically significant. From this it was concluded that the practice effects were effectively controlled in this experimental design.

A series of t ratios, corrected according to McNemar's (22)

TABLE 4

ANALYSIS OF VARIANCE FOR VARIABLES MODIFYING OPTIMAL FLASH-RATE: GROUNDS X ORDER OF PRESENTATION X REPLICATIONS

Source	ss	df	ms	F ratio	F	p
Grounds (G)	1.40	2	0.70	ms_G/ms_{GR}	1.21	-
Order of Presentation (O)	0.06	2	0.03	ms_O/ms_{OR}	0.02	-
Replication	11.80	11	1.07	-	-	-
G X O	1.77	4	0.44	ms_{GO}/ms_{GOR}	0.81	-
G X R	12.71	22	0.58	-	-	-
O X R	35.80	22	1.63	-	-	-
G X O X R	23.54	44	0.54	-	-	-
Within Cells	0.00	0	-	-	-	-
Total	87.08	107	-	-	-	-

TABLE 5

ANALYSIS OF VARIANCE FOR VARIABLES MODIFYING
UPPER FLASH-RATE THRESHOLD: GROUNDS X
ORDER OF PRESENTATION X REPLICATIONS

Source	ss	df	ms	*F* ratio	*F*	*p*
Grounds (G)	8.90	2	4.45	ms_G/ms_{GR}	5.86	0.01
Order of Presentation (O)	0.80	2	0.40	ms_O/ms_{OR}	0.10	-
Replications (R)	45.90	11	4.17	-	-	-
G X O	4.16	4	1.04	ms_{GO}/ms_{GOR}	1.17	-
G X R	16.61	22	0.76	-	-	-
O X R	87.32	22	3.97	-	-	-
G X O X R	39.04	44	0.89	-	-	-
Within Cells	0.00	0	-	-	-	-
Total	202.73	107	-	-	-	-

TABLE 6

ANALYSIS OF VARIANCE FOR VARIABLES MODIFYING RANGE OF MOTION: GROUNDS X ORDER OF PRESENTATION X REPLICATIONS

Source	ss	df	ms	*F* ratio	*F*	*p*
Grounds (G)	11.07	2	5.54	ms_G/ms_{GR}	5.65	0.025
Order of Presentation (O)	1.37	2	0.68	ms_O/ms_{OR}	0.11	-
Replications (R)	50.10	11	4.55	-	-	-
G X O	4.92	4	1.23	ms_{GO}/ms_{GOR}	1.05	-
G X R	21.51	22	0.98	-	-	-
O X R	132.15	22	6.01	-	-	-
G X O X R	51.49	44	1.17	-	-	-
Within Cells	0.00	0	-	-	-	-
Total	272.61	107	-	-	-	-

formula for correlation were computed to determine the significance of difference between the means of the measures of Beta motion. These are presented in Table 7. Three _ts_ were significant ($p < .01$). Two were at the upper threshold between the non-figured and the vertically barred ground, and between the non-figured and the horizontally barred ground. The third was for the range of motion between the non-figured and the vertically barred ground. Two other _t_ ratios were significant ($p < .05$). For the lower limen the significant _ts_ were between the vertically barred and the non-figured ground. For the range of motion the significant _t_ was between the horizontally barred and the non-figured grounds. For the other _t_ ratios, the null hypothesis must be accepted, and it was concluded that these grounds were not a statistically significant source of variance for the means tested.

TABLE 7

SIGNIFICANCE OF THE DIFFERENCES BETWEEN THE MEANS OF THE MEASURES OF BETA MOTION

Measure	Ground	Vertical Ground	Horizontal Ground
Lower Flash-rate Threshold	Non-figured	2.14**	1.33
	Vertical	-	0.71
Optimal Flash-rate	Non-figured	1.87	0.50
	Vertical	-	1.08
Upper Flash-rate Threshold	Non-figured	3.02*	2.76*
	Vertical	-	0.26
Range of Motion	Non-figured	3.02*	2.48**
	Vertical	-	0.46

*Significant at the 0.01 level of confidence, df = 36.

**Significant at the 0.05 level of confidence, df = 36.

CHAPTER IV

DISCUSSION AND CONCLUSIONS

The over-all effect of change in ground for the upper threshold was significant statistically. This may be interpreted as that the grounds did change one limit of Beta motion. The differences between the non-figured and the horizontally barred, and the non-figured and the vertically barred grounds, were significant. It was found that the mean flash-rate for the non-figured ground was 5.26 f/s, while the horizontal and vertical grounds were 4.68 f/s and 4.62 f/s, respectively. In maintaining motion perception a higher rate of motion was tolerated by the S for the plain in comparison with the figured grounds. These differences were statistically significant. The finding is consonant with the hypothesis that more motion may be obtained from the non-figured than from the figured grounds. The hypothesis that there would be a differential perception of Beta motion for the horizontally barred as compared with the vertically barred grounds was rejected.

The other dependent variable for which ground was significant was range. The range was modified mainly by the elevation of rate in the upper limit. There were no statistically significant differences between the means of the measures for the grounds at the lower threshold nor in the optimal flash-rate. There were no statistically significant differences between the horizontally barred and the vertically barred grounds.

Another finding of importance was the consistency of ground effects for the measures of Beta motion. The Pearson product-moment correlation coefficients were significant. For several measures, except for certain ground effects on optimal rate, the obtained rs between the non-figured and vertically barred ground, and between the vertically and horizontally barred grounds were significant beyond the 1 per cent level of confidence. Only the correlation between the non-figured and the horizontally barred grounds for optimal flash-rate was not significant statistically. Moreover, the highest r was obtained at the lower threshold. It may be interpreted as indicating that the Os were most consistent at the lower threshold. These Os were not consistent at the optimal flash-rate measure.

It would appear, then, on the basis of these results, that a flash-rate must have a certain minimum to be perceived as apparent motion under the parameters that have been used in this study. The very high consistency of the O's report at the lower threshold emphasized (for most Os) the constant property of this minimum. These grounds have no important effect on the lower threshold. On this basis, it seems most reasonable that one should look for a physiological rather than a perceptual explanation to understand this portion of the phenomenon (2).

In constructing a physiological model to account for this part of the findings, an hypothesis of a summation of neural impulses taking place in the cerebral cortex was assumed. On the basis of available evidence this seems a safe assumption (2, 23). Now, when the eye is presented with two alternating stimulus lights forming the basis for Beta motion, the light from each of these lights falling on the retina generates a neural impulse which is then transmitted along the visual pathways to the visual cortex, near Brodmann's area _17_ (23). The evidence indicates that each time the light flashes, a train of corticopetal neural impulses is generated, and presumably ends in the visual cortex. According to L. de No's (23) statistical model of the visual pathways, these impulses may be retained in discrete pathways by the processes of summation and inhibition. The model assumes that a relatively strong impulse is necessary to fire a post-synaptic, corticopetal neuron; this strength of impulse may be called the "normal" one. The neural net of the retinae and cortex are connected by a series of neurons. A weak impulse, radiating along these branches, may not have the strength necessary to fire more than one, directly connected post-synaptic neuron. A neuron barely discharging above threshold although impinging on others may not fire them. This processing serves to preserve the discrete nature of the original stimulus object.

However, the model assumes both temporal and spatial summation. The first assumption states that, for two neural impulses discharging on a post-synaptic neuron's dendrites in a particular temporal order, and neither of which are in themselves of sufficient intensity to fire the post-synaptic neuron, a summation may produce a suprathreshold intensity and fire the neuron. The second assumption of spatial summation states that given two subthreshold impulses which arrive on separate dendrites of the post-synaptic neuron at the same time, may summate through the post-synaptic neuron, and thus fire it. It seems probable that this form of summation (spatial) in the visual system operates to provide a smooth, filled-in projection of the external stimulus field, while the first, temporal summation, operates to provide a smooth, continuous percept of real motion in the external stimulus field.

In this model, as the stimulus lights for Beta motion are driven at a very low flash-rate, e.g., about 1 f/s, a wave of excitation is set up in the retinae for each flash of each light. This, in turn, fires the succeeding corticopetal neurons, and the impulse eventually ends on the cortical neurons. But there is also a series of impulses set up which impinge on the dendrites of the adjacent cortical neurons in the visual striate area. With such a low rate of flashing, these do not form the sequence apparently needed for summation to take place; nor are the two stimulus lights close enough together spatially so that the impulses aroused by the stimulation of the retina impinge on the same internuncial neurons. As the flash-rate increased, the impingement of these impulses on adjacent neurons becomes more and more frequent; finally, a rate is reached which allows temporal summation to take place. Then the area of stimulation is spread a little, and other sets of internuncial neurons begin to be given some subthreshold stimulation. As the flash-rate is further increased, the same mechanism involves more and more neurons. A locus of excitation is set up. As this locus is enlarged with increasing flash-rate, it may begin to interact with the locus which has been set up by the stimulation of the second stimulus light. Finally, the two loci in the usual cortex interact through a "band" of neurons between them, and no longer discrete points are present. The percept under these conditions may be of a single light which swings back and forth, following in its trajectory the band of stimulation which has been caused by the interaction of the loci set up by each light.

This neurally oriented explanation seems to fit the facts obtained in this study for the lower flash-rate threshold. It is consonant with the finding of the highest correlation coefficients at the lower flash-rate threshold. After all, the nervous system does seem to have rather stable time constants under which summation can take place (23). The interpretation appears to be in agreement with the analyses of variance and the _t_ test findings, both of which show that there is no significant difference for ground at the lower flash-rate threshold; it is flash-rate which is the important parameter, and not the patterning of the grounds through which the Beta motion takes place. It is, then, a neural, not a perceptual, phenomenon which takes place at the lower threshold.

On the upper limit of apparent motion there are statistically significant differences in the means of the motion seen against the fixed grounds used in this study. These differences are in each case between the figured and the non-figured grounds. In comparing directly the obtained means for this measure of apparent motion, it was found that more motion was seen on the non-figured as compared to the figured grounds. It was earlier hypothesized that this might take place on the basis of a [isomorphic] projection of the stimulus ground to the cortex in such a way that the non-figured ground would present the greatest possible number of alternative pathways by which apparent motion could take place. Therefore, more motion should be seen on this than on the other two grounds. Whether or not there may be strict "isomorphism" of the visual ground in all its particulars may not be interpreted directly from this study. But by attaching the strips of opaque paper to the grounds the illuminated area was reduced. One explanation of the findings may be that summation functions at and beyond the upper flash-rate threshold on a temporal basis alone. Well defined lights flickering almost simultaneously produces two sensations. Summation by area, providing these areas are spatially separated, fails to link the two defined brightness levels together into motion perception. In varying the intensity for the stimulus lights, Saucer (30) found that intensity did not affect the mean duration of motion. It seems reasonable to relate this fact to this problem. Perhaps ground intensity, not a significant variable in itself, could operate only as a spatial variable if it operated at all. The higher stimulation rate, with summation on a temporal basis at the cortical level, produced two flickering lights and the upper limit in reality represents a lower fusion threshold of a special type. The ground properties were supposedly effective in possibly altering fusion in terms of temporal summation. This study suggests a central sensitization on a temporal basis at the upper margin of motion- no motion thresholds. The hypothesis of temporal summation advanced by Horne, et al (15), is partially supported in this study.

CHAPTER V

SUMMARY

Two figured grounds, one vertically barred and a second horizontally barred, and a non-figured ground were used to determine the mean upper and lower flash-rate thresholds, an optimal rate, and the range of flash-rates within which Beta apparent motion may be seen. Several hypotheses were developed: (1) there should be little motion seen with the vertically barred ground, it serving as a perceptual barrier to the production of apparent motion; (2) that the horizontally barred ground should have an intermediate amount of apparent motion, the horizontal bars parallel to the path to be taken by the Beta motion furnishing perceptual pathways for motion; and (3) that the non-figured ground, by providing the largest free area, should provide the maximum amount of apparent motion.

The resulting measures were subjected to several statistical analyses consisting of the means, the standard deviations, the standard errors of the means, Pearson product-moment correlation coefficients between pairs of the measures, _t_ ratios to evaluate the significance of the differences between the obtained means, and four complex analyses of variance to evaluate the over-all significance of the sources of variance, and _t_ ratios corrected for correlation to evaluate the differences between the means of the measures of apparent motion, for 36 _Ss_.

It was found that no statistically significant differences obtained between the grounds on the lower threshold, and for the optimal flash-rate. Statistically significant differences were found at the upper threshold and for the range within which Beta motion may be seen between the figured and the non-figured grounds used in this study. No statistically significant differences were obtained between the horizontally and vertically barred grounds. Statistically significant _r_s were found between all the pairs of measures except for the optimal flash-rate. This finding was related to the consistency of _O_s reports and thus of the stability of the measures used. The finding of statistically significant differences between the figured and the unfigured grounds at the upper threshold were related to a theory of summation based on: (1) flash-rate, and (2) the area stimulated. (This finding was also related to L. de No's theory of the statistical nature of discrete stimulation on the visual pathways.)

A Gestalt interpretation of Beta-type apparent motion on the basis of _prägnanz_ and of isomorphism was questioned. Temporal processes at a central locus or loci may more readily be used for motion and flicker-fusion interpretations.

APPENDIX A

GRAECO-LATIN SQUARE DESIGN

Order of Presentation	Backgrounds:			Subjects Assigned
	Plain	Vertical	Horizontal	
1 (Plain, Vertical, Horizontal)	1	2	3	1, 4, 7, 10, 13, 16, 19, 22, 25, 28, 31, 34, 7A, 25A.*
2 (Horizontal, Plain, Vertical)	2	3	1	2, 5, 8, 11, 14, 17, 20, 23, 26, 29, 32, 35, 11A, 20A.
3 (Vertical, Horizontal, Plain)	3	1	2	3, 6, 9, 12, 15, 18, 21, 24, 27, 30, 33, 36, 15A, 18A, 27A.

*Suffix indicates a replacement subject.

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BIOGRAPHICAL ITEMS

The writer was born on March 2, 1926, at Ironton, Ohio. He pursued his undergraduate studies at the University of Florida, receiving the B.A. degree June 7, 1954. He entered the Graduate School at the University of Florida, receiving the M.A. degree in the College of Arts and Sciences, Department of Psychology, June 4, 1956.

He has served as a graduate assistant in the Department of Psychology, as a research and laboratory assistant from September, 1955, to September, 1957, when he received a Fellowship under the Vocational Rehabilitation Traineeship program. He is currently serving as a trainee in the Veteran's Administration program in Psychology.

In 1955 he was elected to the Beta chapter, Alpha Kappa Delta, Honorary Sociology Fraternity. In 1956 he was elected to membership in the Florida Psychological Association. He was elected to associate membership in the American Psychological Association in 1958.

This dissertation was prepared under the direction of the Chairman of the Supervisory Committee and has been approved by all members of the committee. It was submitted to the Dean of the College of Arts and Sciences and to the Graduate Council and was approved as partial fulfillment of the requirements for the degree Doctor of Philosophy.

January 31, 1959

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Dean, Graduate School

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